Chapter 9

Robotics in Healthcare: A Brief Introduction

Bilge Büyükşirin[1]

Abstract

In recent years, robotics has emerged as a transformative force in the field of healthcare. As technology continues to advance, robots are playing an increasingly vital role in patient care, diagnosis, surgery, and rehabilitation. This study explores the various applications of robotics in healthcare, highlighting its potential to revolutionize the way we approach medical treatment and improve patient outcomes.

1. Introduction

Instruments used in healthcare operations have long history as medicine itself. It is known that medical instruments such as scalpels, lancets, curettes, tweezers, tubes and surgical knives made from bone, bronze, silver and iron were used in ancient Egypt and Rome. By time and technical developments medicine got developed and divided into many branches. And with new branches of medicine many specialized tools were invented for special operations. After invention of electronics and especially computers, automatized tools were started to be used in healthcare.

Robots are defined as a programmable machines which can accomplish complex mechanical tasks by itself. In medicine robots are used in rehabilitation, surgical, telepresence, drug supply, social assistance, imaging, disinfection, radiotherapy, transport and similar operations. Morgan et al. (2022) stated that rehabilitation and surgical applications are first two areas where most of the robotics studies are conducted.

In this study robotic applications used in healthcare are examined in three sections by their popularity. In first section rehabilitation and mobility robots, in second section surgical robots and in third section robots used in other operations are investigated.

1 Department of Healthcare Management, 37521 Trakya University, Edirne, Turkey.
ORCID: 0000-0002-3941-7339, e-mail: bilgebuyuksirin@trakya.edu.tr

https://doi.org/10.58830/ozgur.pub305.c1254

2. Rehabilitation and Mobility Robots

Rehabilitation and mobility robots are designed and used to assist patients who have difficulty in performing physical activities, increase muscle strength and power, strengthen muscle-brain communication, and aid patients in various rehabilitation exercises. Rehabilitation and mobility robots have various designs to support body weight of the patient and to assist movement of limbs. In Fig.1 several designs are illustrated. In Fig.1a body weight of the patient is supported by a harness attached to celling and movement of the lower limbs are assisted by an exoskeleton. In Fig.1b similar to first setup body weight is supported by celling attached harness but movement of the feet is assisted by actuated programmable plates. In Fig.1c body weight of the patient is supported by a mobile robotic frame which can adapt and follow to movements of the patient. In Fig.1d body weight of the patient is supported by a mobile frame and movement of the limbs of the patient is assisted by an exoskeleton. In Fig.1e a self-balanced exoskeleton is used for both supporting body weight and movement assist. In Fig.1f and Fig.1g patient has a sitting position and treated limbs are assisted by an upper or lower limbs exoskeleton. Finally in Fig.1h a foot orthotics is shown which can be used while walking, standing or sitting.

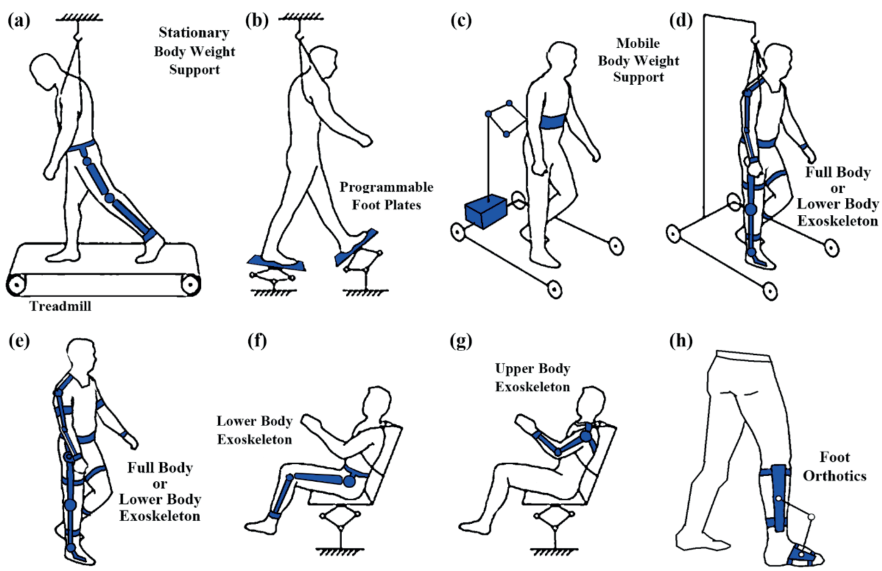

Figure 1. Rehabilitation and mobility robot designs.

It is reported that there are more than one hundred robot systems used in rehabilitation and mobility applications indexed in literature (Morgan et al., 2022). The rehabilitation and mobility robots may have the designs given in Fig.1a-h or any combination of them. In table-1 some of the common rehabilitation and mobility robots, their usages, their creators and their types are listed. These devices provide personalized therapy and can adapt to the patient's progress, making the recovery process more efficient and effective.

Table-1. Rehabilitation and Mobility Robots

Robot Name	**Purpose**	**Company/ Creators**	**Type**
Lokomat (Jezernik et al., 2003)	lower limbs rehabilitation	Hocoma AG	Fig.1a
HAL (Suzuki et al., 2007)	exoskeleton, mobility assistance, upper-lower limbs rehabilitation	Cyberdyne	Fig.1e
Hunova (Saglia et al., 2019)	rehabilitation and the sensorimotor assessment of the lower limbs and trunk	Movendo technology	Fig.1b Fig.1f
LokoHelp (Freivogel et al., 2008)	gait-training, postural training	Woodway	Fig.1a
ReoAmbulator (Calabrò et al., 2016)	gait rehabilitation, ambulation rehabilitation, coordination rehabilitation	Motorika	Fig.1a
ALEX (Banala et al., 2008)	neuromotor rehabilitation of upper limb function	Kinetek	Fig.1g
LOPES (Meuleman et al., 2015)	gait training for stroke patients	University of Twente	Fig.1a
String-Man (Surdilovic and Bernhardt, 2004)	posture balancing, gait assistance	Fraunhofer Institute	Fig.1a
Gangtrainer GT (Hesse et al., 2008)	gait trainer	Reha-Stim	Fig.1b
HapticWalker (Schmidt et al., 2008)	gait trainer	Fraunhofer Institute	Fig.1b
GaitMaster5 (Tanaka et al., 2012)	gait assistance, feet rehabilitation	University of Tsukuba	Fig.1b Fig.1h
KineAssist (Patton et al., 2008)	gait assistance	Kinea Design LLC	Fig.1c
WalkTrainer (Allemand et al., 2009)	gait assistance	Swortec SA	Fig.1d
ReWalk (Awad et al., 2020)	gait assistance	ARGO Medical	Fig.1e
NUVABAT (Ding et al., 2010)	ankle rehabilitation, measurement of ankle kinematics	Northeastern university	Fig.1b Fig.1f

3. Surgical Robots

Surgery is defined as a medical procedure which involves cutting the patient's tissues to reach the inner parts of the body, threading a health problem and closing of the wounds. Surgical operations categorized as invasive procedures where external tools are used inside the patient's body through a cut. Conventional surgical operations which also named as open surgery usually need large incisions to access the diseased area and exposes internal body cavity to outside. Because of the large incisions patient's recovery takes long time and risk of infection and complications arise. To reduce these risks during operation the size of the incision can be minimized. Which is called as minimally invasive surgery, where surgery tools got reached to the inner parts of the body through natural orifices or small holes pierced to the tissue. Using minimally invasive surgery is more advantageous for patients but still may get tiring for the operator. The advanced surgical robots specially designed for specific procedures and operations make the operator`s job much easier. These robots offer enhanced dexterity, 3D visualization, and reduced surgical trauma, resulting in shorter recovery times and less pain for patients. As a result, complex surgeries are becoming safer and more accessible.

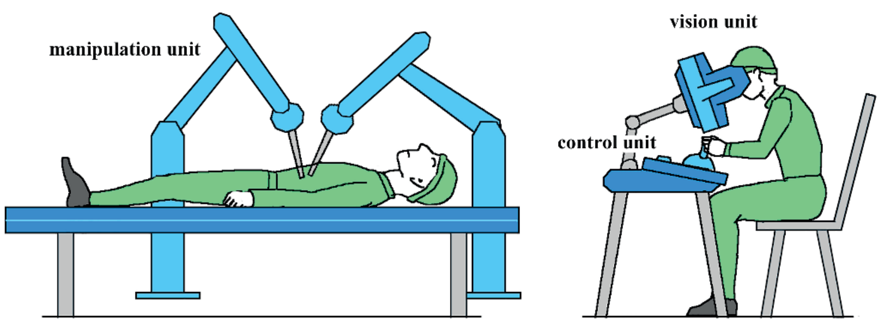

Figure 2. General units of surgical robots.

Surgical robots generally have three main units as the manipulator unit, the controller unit and the vision unit. The manipulator unit is the main actuation unit of the robot, which holds and moves the surgical tools. Manipulation unit can be made of 6 or 7 degrees of freedom robot arms or specially designed mechanisms. Surgical tools such as scalpels, forceps, retractors and clamps are got attached to end effectors of the robot arms.

Besides these tools end effectors also contain sensors and cameras to give information and vision to the operator. The operator controls the arms or mechanisms through the controller unit. The advanced controller units usually have haptic feedback property for sensing the tissue and movements. During operation the operator watches the operation through the vision unit. The operator can be in the same place with the patient or can be in another location and control the robots online. Advanced vision units provide 3d view beside conventionally 2d view.

Table-2. Surgical Robots

Robot Name	Surgery purpose	Company/Creators	Image
da Vinci surgical system (Freschi et al., 2013)	urology, laparoscopy, gynecology, thoracoscopy,	Intuitive Surgical Inc	Fig.2a (Intuitive, 2023)
MiroSurge (Konietschke et al., 2009)	laparoscopy	DLR robotics	Fig.2b (DLR, 2018)
Versius robotic system (Dixon et al., 2021)	gynecology, colorectal, renal, laparoscopy	CMR Surgical	Fig.2c (CMR, 2023)
Senhance (Samalavicius et al., 2020)	gynecology, laparoscopy	TransEnterix, Asesnsus	Fig.2d (Asensus, 2023)
Monarch Platform (Graetzel et al., 2019)	bronchoscopy	Auris Surgical Robotics	Fig.2e (Ethicon, 2023)
Flex® robotic system (Mattheis et al., 2017)	oropharynx, hypopharynx, larynx	Medrobotics Corp	Fig.2f (Medrobotics, 2018)
Sensei X robotic catheter system (Rolls et al., 2014)	cardiac catheter insertion	Hansen Medical Inc	Fig.2g (Hansenmedical, 2016)
NeoGuide Colonoscope (Eickhoff et al., 2007)	colonoscopy	Intuitive Surgical Inc	Fig.2h (Farnam, 2012)
Invendoscopy E200 system (Groth et al., 2011)	colonoscopy	Invendo Medical GmbH	Fig.2i (Invendo, 2015)
FreeHand v1.2 (Stolzenburg et al., 2011)	laparoscopy, thoracoscopy	Freehand Surgeon Ltd	Fig.2j (Freehandsurgeon, 2023)

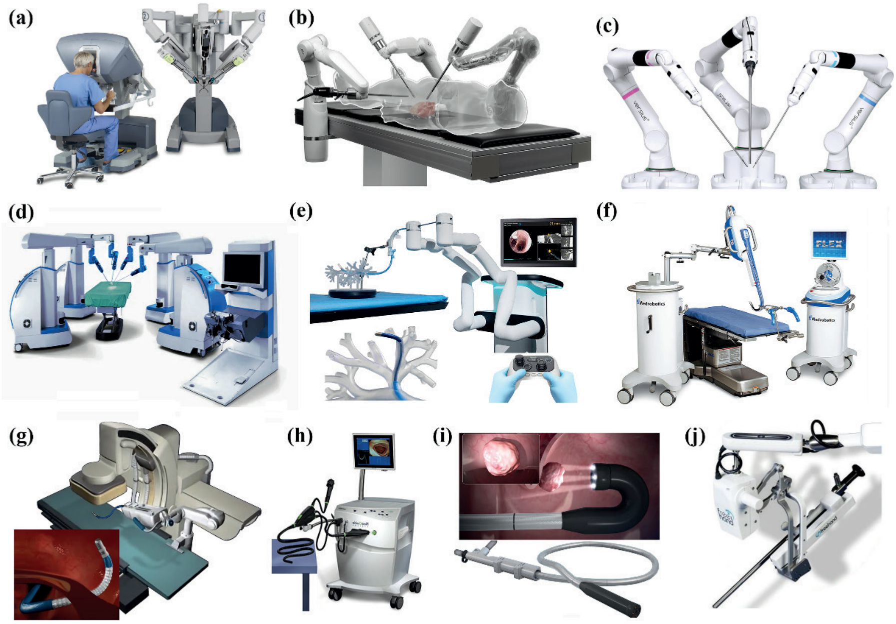

Figure 3. Commercial surgical robots.

Some of commercial surgical robots are listed in Table-2 and their images are presented in Fig.3. From these robots da Vinci, Senhance, MiroSurge and Versius robotic systems use multiple robot arms. At these systems one of the arms holds the cameras and provides information and vision to operator. While other arms are used for manupulation of the surgical tools. Other robots on the list are special mechanisms consisting of snake-like actuators with multiple degrees of freedom, used to explore body cavities such as the lungs, stomach, intestines, and main veins and to perform operations in these cavities. The FreeHand system is actually a robot assisted vision system, which helps the operator to get a clear view of the inner body.

4. Robots Used in Other Operations

4.1. Drug Delivery and Pharmacy Automation

Automation plays a significant role in drug preparation and delivery. Robotic systems are used in pharmacies to dispense medication with high accuracy, reducing the risk of errors. Moreover, tiny robotic devices are being developed for targeted drug delivery within the body, enabling precise treatment of diseases while minimizing side effects (Li et al., 2016).

In addition to these small-sized robots, mobile robots that carry equipment are among the robotic systems trying to gain a place in the healthcare industry. While these mobile robots automate routine tasks in the hospital on the other hand they are used to deliver medicine and equipment to quarantine areas where entry and exit are prohibited.

4.2. Telemedicine and Remote Monitoring

Robots are also facilitating remote healthcare delivery. Telemedicine robots equipped with cameras and sensors allow doctors to interact with patients from a distance (Koceska et al., 2019). This is particularly valuable in situations where physical presence is challenging, such as during a pandemic. Additionally, robots can monitor patients in their homes, collecting data and alerting healthcare providers to any concerning changes in real-time, thus improving the management of chronic conditions.

4.3. Socially Assistive Robots

Socially assistive robots are developed to aid humans through social interactions and guidance in various environments (Vulpe et al., 2021). These robots usually take cute animal shapes or humanoid forms. With their AI support they can take voice commands and even perform long chats with users. They are designed to guide and inform users about a procedure, location, treatment or similar. Some current research attempts to design these robots to provide psychological support and make them a part of treatment.

4.4. Radiotherapy Robots

Radiotherapy is one of the most widely used cancer treatment. Effectiveness of high energy X-rays over the cancer cells is proven by many applications. But while these rays are killing the cancer and tumor cells they are also damaging the healthy cells of the patient. This is the undesirable and most feared side effect of the radiotherapy. Fortunately, robotic radiotherapy overcame this draw back by sending concentrated rays only to the treatment area, and adapting itself to patient (Crop et al., 2015).

5. Conclusion

Robotics in healthcare is ushering in a new era of medical practice. From the operating room to remote consultations, robots are improving the quality of care, enhancing patient experiences, and increasing the efficiency of healthcare systems. As technology continues to evolve, the potential for robotics to transform healthcare is limitless. However, it is essential to strike a balance between technological innovation and ethical considerations to ensure that the benefits of robotics are harnessed while maintaining the human touch in patient care. The future of healthcare undoubtedly includes robots as valuable partners in delivering the best possible medical services to patients worldwide.

References

Allemand, Y., Stauffer, Y., Clavel, R., and Brodard, R. (2009). Design of a new lower extremity orthosis for overground gait training with the WalkTrainer. 2009 IEEE International Conference on Rehabilitation Robotics,

Asensus. (2023). *Senhance surgical system*. https://asensus.com/

Awad, L. N., Esquenazi, A., Francisco, G. E., Nolan, K. J., and Jayaraman, A. (2020). The ReWalk ReStore™ soft robotic exosuit: a multi-site clinical trial of the safety, reliability, and feasibility of exosuit-augmented post-stroke gait rehabilitation. *Journal of neuroengineering and rehabilitation*, *17*, 1-11.

Banala, S. K., Kim, S. H., Agrawal, S. K., and Scholz, J. P. (2008). Robot assisted gait training with active leg exoskeleton (ALEX). *IEEE transactions on neural systems and rehabilitation engineering*, *17*(1), 2-8.

Calabrò, R. S., Cacciola, A., Bertè, F., Manuli, A., Leo, A., Bramanti, A., Naro, A., Milardi, D., and Bramanti, P. (2016). Robotic gait rehabilitation and substitution devices in neurological disorders: where are we now? *Neurological Sciences*, *37*, 503-514.

CMR. (2023). *Versius robotic system*. https://cmrsurgical.com/

Crop, F., Lacornerie, T., Mirabel, X., and Lartigau, E. (2015). Workflow optimization for robotic stereotactic radiotherapy treatments: application of constant work in progress workflow. *Operations Research for Health Care*, *6*, 18-22.

Ding, Y., Sivak, M., Weinberg, B., Mavroidis, C., and Holden, M. K. (2010). Nuvabat: northeastern university virtual ankle and balance trainer. 2010 IEEE Haptics Symposium,

Dixon, F., Khanna, A., Vitish-Sharma, P., Singh, N. S., Nakade, K., Singh, A., Qureshi, A., O'Hara, R., and Keeler, B. D. (2021). Initiation and feasibility of a multi-specialty minimally invasive surgical programme using a novel robotic system: A case series. *International Journal of Surgery*, *96*, 106182.

DLR. (2018). *Miro Surge*. https://www.dlr.de/rm/en/desktopdefault.aspx/tabid-11674/#gallery/28728

Eickhoff, A., Van Dam, J., Jakobs, R., Kudis, V., Hartmann, D., Damian, U., Weickert, U., Schilling, D., and Riemann, J. F. (2007). Computer-assisted colonoscopy (the NeoGuide Endoscopy System): results of the first human clinical trial ("PACE study"). *Official journal of the American College of Gastroenterology| ACG*, *102*(2), 261-266.

Ethicon. (2023). *Monarch bronchoscopy platform* https://www.jnjmedtech.com/en-US/product-family/monarch

Farnam, J. (2012). *NeoGuide colonoscopy system*. https://www.coroflot.com/Who_is_this_man/NeoGuide-endoscopy-system

Freehandsurgeon. (2023). *FreeHand V1.2*. https://www.freehandsurgeon.com/

Freivogel, S., Mehrholz, J., Husak-Sotomayor, T., and Schmalohr, D. (2008). Gait training with the newly developed 'LokoHelp'-system is feasible for non-ambulatory patients after stroke, spinal cord and brain injury. A feasibility study. *Brain Injury*, *22*(7-8), 625-632.

Freschi, C., Ferrari, V., Melfi, F., Ferrari, M., Mosca, F., and Cuschieri, A. (2013). Technical review of the da Vinci surgical telemanipulator. *The International Journal of Medical Robotics and Computer Assisted Surgery*, *9*(4), 396-406.

Graetzel, C. F., Sheehy, A., and Noonan, D. P. (2019). Robotic bronchoscopy drive mode of the Auris Monarch platform. 2019 International Conference on Robotics and Automation (ICRA),

Groth, S., Rex, D. K., Rösch, T., and Hoepffner, N. (2011). High cecal intubation rates with a new computer-assisted colonoscope: a feasibility study. *The American journal of gastroenterology*, *106*(6), 1075.

Hansenmedical. (2016). *Sensei X robotic catheter system*. http://www.hansenmedical.com/

https://www.youtube.com/@hansenmedical

Hesse, S., Mehrholz, J., and Werner, C. (2008). Robot-assisted upper and lower limb rehabilitation after stroke: walking and arm/hand function. *Deutsches Ärzteblatt International*, *105*(18), 330.

Intuitive. (2023). *da Vinci surgical system*. https://www.intuitive.com/en-us/products-and-services/da-vinci

Invendo. (2015). *Invendoscopy E200 system* https://www.youtube.com/@invendomedical

Jezernik, S., Colombo, G., Keller, T., Frueh, H., and Morari, M. (2003). Robotic orthosis lokomat: A rehabilitation and research tool. *Neuromodulation: Technology at the neural interface*, *6*(2), 108-115.

Koceska, N., Koceski, S., Beomonte Zobel, P., Trajkovik, V., and Garcia, N. (2019). A telemedicine robot system for assisted and independent living. *Sensors*, *19*(4), 834.

Konietschke, R., Hagn, U., Nickl, M., Jorg, S., Tobergte, A., Passig, G., Seibold, U., Le-Tien, L., Kubler, B., and Groger, M. (2009). The DLR MiroSurge-A robotic system for surgery. 2009 IEEE international conference on Robotics and automation,

Li, H., Go, G., Ko, S. Y., Park, J.-O., and Park, S. (2016). Magnetic actuated pH-responsive hydrogel-based soft micro-robot for targeted drug delivery. *Smart Materials and Structures*, *25*(2), 027001.

Mattheis, S., Hasskamp, P., Holtmann, L., Schäfer, C., Geisthoff, U., Dominas, N., and Lang, S. (2017). Flex robotic system in transoral robotic surgery: the first 40 patients. *Head & neck*, *39*(3), 471-475.

Medrobotics. (2018). Flex robotic system http://www.medrobotics.com/

Meuleman, J., Van Asseldonk, E., Van Oort, G., Rietman, H., and Van Der Kooij, H. (2015). LOPES II—design and evaluation of an admittance controlled gait training robot with shadow-leg approach. *IEEE transactions on neural systems and rehabilitation engineering*, *24*(3), 352-363.

Morgan, A. A., Abdi, J., Syed, M. A., Kohen, G. E., Barlow, P., and Vizcaychipi, M. P. (2022). Robots in healthcare: a scoping review. *Current Robotics Reports*, *3*(4), 271-280.

Patton, J., Brown, D. A., Peshkin, M., Santos-Munné, J. J., Makhlin, A., Lewis, E., Colgate, E. J., and Schwandt, D. (2008). KineAssist: design and development of a robotic overground gait and balance therapy device. *Topics in stroke rehabilitation*, *15*(2), 131-139.

Rolls, A. E., Riga, C. V., Bicknell, C. D., Regan, L., Cheshire, N. J., and Hamady, M. S. (2014). Robot-assisted uterine artery embolization: a first-in-woman safety evaluation of the Magellan System. *Journal of Vascular and Interventional Radiology*, *25*(12), 1841-1848.

Saglia, J. A., De Luca, A., Squeri, V., Ciaccia, L., Sanfilippo, C., Ungaro, S., and De Michieli, L. (2019). Design and development of a novel core, balance and lower limb rehabilitation robot: Hunova®. 2019 IEEE 16th International Conference on Rehabilitation Robotics (ICORR),

Samalavicius, N. E., Janusonis, V., Siaulys, R., Jasėnas, M., Deduchovas, O., Venckus, R., Ezerskiene, V., Paskeviciute, R., and Klimaviciute, G. (2020). Robotic surgery using Senhance® robotic platform: single center experience with first 100 cases. *Journal of robotic surgery*, *14*, 371-376.

Schmidt, H., Krüger, J., and Hesse, S. (2008). HapticWalker—Haptic foot device for gait rehabilitation. *Human Haptic Perception: Basics and Applications*, 501-511.

Stolzenburg, J. U., Franz, T., Kallidonis, P., Minh, D., Dietel, A., Hicks, J., Nicolaus, M., Al-Aown, A., and Liatsikos, E. (2011). Comparison of the FreeHand® robotic camera holder with human assistants during endoscopic extraperitoneal radical prostatectomy. *BJU international*, *107*(6), 970-974.

Surdilovic, D., and Bernhardt, R. (2004). STRING-MAN: a new wire robot for gait rehabilitation. IEEE International Conference on Robotics and Automation, 2004. Proceedings. ICRA'04. 2004,

Suzuki, K., Mito, G., Kawamoto, H., Hasegawa, Y., and Sankai, Y. (2007). Intention-based walking support for paraplegia patients with Robot Suit HAL. *Advanced Robotics*, *21*(12), 1441-1469.

Tanaka, N., Saitou, H., Takao, T., Iizuka, N., Okuno, J., Yano, H., Tamaoka, A., and Yanagi, H. (2012). Effects of gait rehabilitation with a footpad-type locomotion interface in patients with chronic post-stroke hemiparesis: a pilot study. *Clinical Rehabilitation*, *26*(8), 686-695.

Vulpe, A., Crăciunescu, R., Drăgulinescu, A.-M., Kyriazakos, S., Paikan, A., and Ziafati, P. (2021). Enabling security services in socially assistive robot scenarios for healthcare applications. *Sensors*, *21*(20), 6912.